FINAL REPORT
DOE Project DE-FG07-98ID13644

Project Title: Intelligent Automated Nuclear Fuel Pellet Inspection System

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EXECUTIVE SUMMARY

At the present time, nuclear pellet inspection is performed manually using naked eyes for judgment and decision making on accepting or rejecting pellets. This current practice of pellet inspection is tedious and subject to inconsistencies and error. Furthermore, unnecessary re-fabrication of pellets is costly and the presence of low quality pellets in a fuel assembly is unacceptable. To improve the quality control in nuclear fuel fabrication plants, an automated pellet inspection system based on advanced techniques is needed. Such a system addresses the following concerns of the current manual inspection method: 1) the reliability of inspection due to typical human errors, 2) radiation exposure to the workers, and 3) speed of inspection and its economical impact.

The goal of this research work is to develop an automated nuclear fuel pellet inspection system which is based on pellet video (photographic) images and uses artificial intelligence techniques.

A prototype of an off-line automatic inspection for quality control of fuel pellet system is developed. The system examines photographic images of pellets using three artificial intelligence techniques for image analysis and defect classification. Figures 3 to 6 show the user interface of this inspection system. The results for fuzzy logic (Figure 4), neural networks (Figure 5), and decision tree (Figure 6) techniques are all indicative of the feasibility and potential that these techniques offer for an advanced inspection system. The prototype system is Web-based and is built using Java programming language.

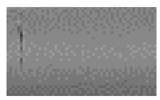
A patent disclosure has been filed with the University of Missouri patent office. Two publications and one Ph.D. dissertation also resulted from this project and are listed below:

- Keyvan, S., Song, X., and Kelly, M. “Computerized Monitoring & Inspection,” Wiley Encyclopedia of Electrical and Electronics Engineering, Vol. 4, pp 1-8,1999.
- Keyvan, S., Song, X., and Kelly, M. “A Nuclear Fuel Pellet Automated Inspection System using Artificial Intelligence,” International conference on Industrial Automation, Montreal, Canada, June 7-9, 1999.
- Song, X. “Nuclear Fuel Pellet Quality Control using Artificial Intelligence Techniques,“ Ph.D. dissertation, University of Missouri-Rolla, November 1999.

SPECIFIC OBJECTIVES AND ACCOMPLISHMENTS

The main objective of this NEER project is to demonstrate the feasibility of fuel pellet inspection using photo images and artificial intelligence techniques. This objective was accomplished by studying the actual pellet images captured through photographic slides and using three techniques, namely, fuzzy logic, decision tree, and neural networks. Pellet images were captured by a camera with a special lighting set up in a laboratory environment.

Generally there are four types of defects in these pellets: 1) chip, 2) crack, 3) banded, and 4) end defect. These defects appear at any location on the pellet surface image with different intensity, size, shape, and background noise. This project focused on the feasibility study in identifying good versus bad pellets, as well as, in identifying the type of defects.



chip defect crack defect banded defect end defect

Figure 1. Four different defects in nuclear fuel pellets

A total of 252 pellets with various defects were available for this research work. Each pellet was photographed 4 times at rotations of 90 degrees. The resultant black and white negatives were scanned into the computer in 256 grayscale mode. Figure 1 shows a sample of these pellet photo images with four different defects.

Figure 2 shows the two parts of the research for this study. The specific objectives accomplished are: 1) from the pellet image develop features appropriate for this study, 2) perform a feasibility study on the concept of using decision tree, fuzzy logic, and neural network for identification of various defects in fuel pellets, 3) develop a data base of various possible fuel defects, and 4) integrate the photographic image analysis with the data base for defect classification using expert system.

Part one of the work encompasses the “image processing” aspect as shown in Figure 2. This part involves 1) on-line digitization of pellet images, and 2) development of an algorithm for enhancement of defects and feature extraction. The most challenging aspect of this part was the development of a dynamic reference model. This involved finding a reference model for a pellet so that any other parts in this pellet that was different from the reference model would represent a defect. In our approach this reference model was represented by the best column pixels of the pellet image. Thus, we searched for a reference column for each pellet independently as it was examined, thus using a dynamic or adaptive approach. The mechanism involved was to monitor the distribution shape of each column of input image pixels and determine the degree of match with the distribution from a good pellet. Then the best column, i.e., the one closest to reference good pellet distribution shape was chosen.

Defect enhancement involved removal of noise and enhancement of the defect part in the image. Our technique is a dynamic one as opposed to the traditional thresholding technique which uses a fixed threshold value for all images. This traditional approach for enhancement would not be applicable to our case. The reason is that in pellet inspection, due to various defect shapes, location, and effect of light on images, one can not use a reference image for comparison with other pellet images. Our approach was to use the pellet local reference model, then, every pixel column of the pellet image was checked against this reference model. Pixel values above or below the reference column were increased or decreased respectively to enhance the defect.

The last task in this part was "Feature Extraction." Features are less sensitive to the encountered variety of the original noisy gray-scale images and provide data reduction while preserving the information required for the inspection. Our approach for feature extraction was typical machine vision techniques, namely, simple edge detection, line tracing, and object shape properties. Features that were extracted from the enhanced image included: area size, shape, location, relative position of light versus dark areas.

Part two encompasses "Defect Recognition." Defect recognition and classification are carried out by three methods, fuzzy logic, decision tree, and neural network.

A major challenge in Part two was the development of algorithms for fuzzy logic, decision tree, and neural network techniques, as well as, a study on their feasibility and potential for defect recognition. In addition, an algorithm for input pre-processing including discritization and encoding method had to be developed and tested for the neural network approach. The Fuzzy Reasoning technique required two steps: 1) processing the features for input to fuzzy reasoning (i.e. Fuzzyfication), and 2) development of an algorithm for classification by Fuzzy Reasoning. For the decision tree algorithm, we used ID3, a common decision tree learning algorithm.

The image processing part was successfully completed. Algorithms for all three techniques, namely, fuzzy logic, neural networks, and decision tree are developed and successfully tested. A prototype of this inspection system is developed. The system examines photographic images of pellets using the above mentioned techniques for image analysis and defect classification. Figure 3 shows the Graphical User Interface (GUI) of this inspection system. The left side of the interface window provides a navigation tree. Each node is linked to a related component, including possible defects in a fuel pellet, inspection methods, previous research and visual inspection, providing several options for the user to choose from. The right side is the GUI of the inspection system and shows a batch of pellet images with their identifier tagging name. The user can either 1) select one pellet at a time by dragging it to the pellet location under "individual pellet view" or 2) choose a method under "Options" and click on the "Inspection All" button to check the status of all available pellet images currently on file[1]. Results of the "Inspection All" selection by the three different techniques are shown in Figures 4 to 6. As shown in these figures, the total number of pellet images under each defect category is provided under "Pellet Information" heading. Furthermore, a table called "Inspection Result" provides the status (good vs. bad) of each individual pellet image with an associated degree of certainty and appears at the top right corner of the GUI.

[1] There are currently 160 total pellet images with 68 good, 46 chipped, 25 end defect, 21 banded defect, and 0 cracks.

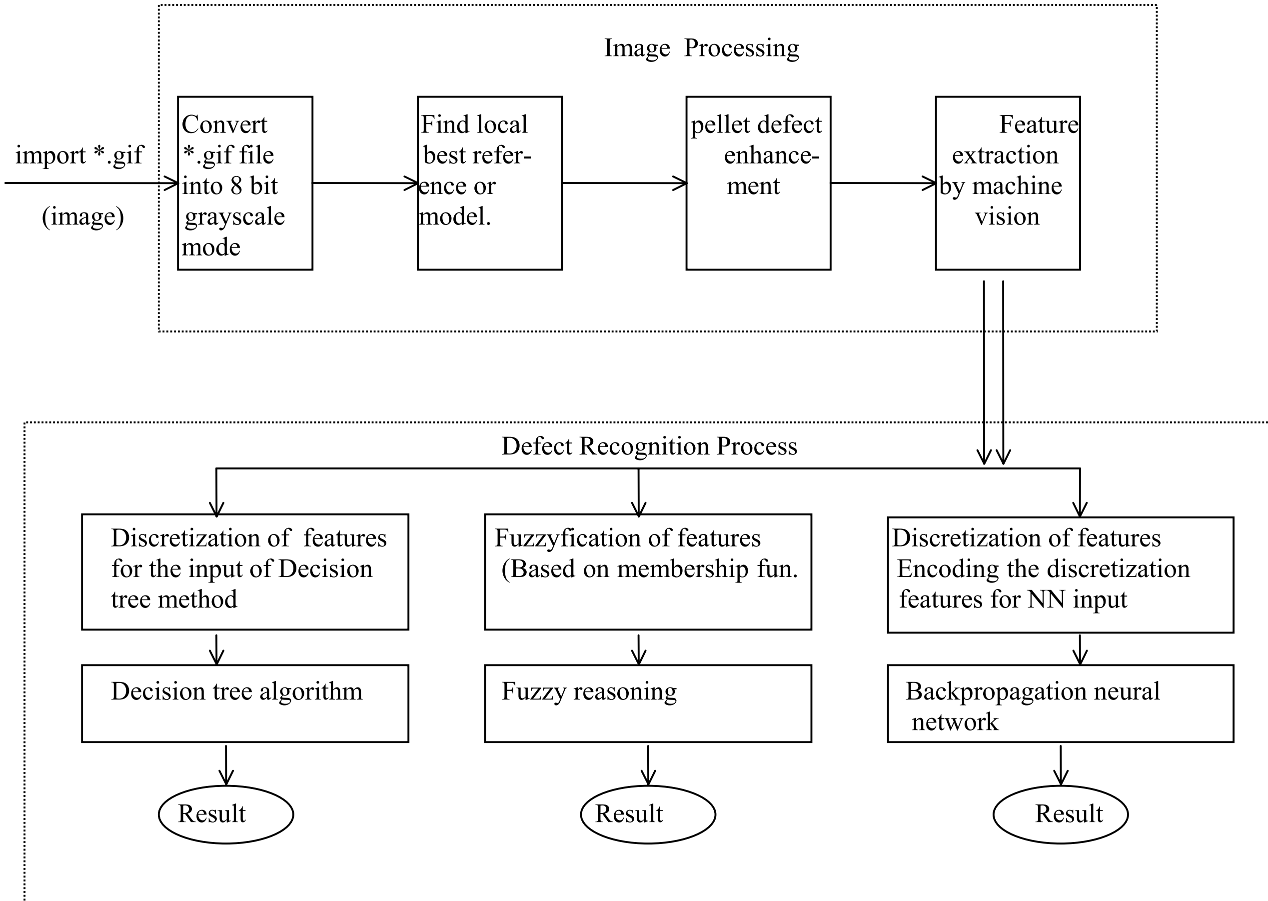


Figure 1. The algorithmic mechanism of the visual inspection system

This prototype system is Web-based and is built using Java programming language.

The results of this project show that artificial intelligence techniques have a high potential for quality control and defect identification of nuclear fuel pellets. Furthermore, these techniques have the potential to drastically speed up the inspection process and strengthen the feasibility of developing an on-line inspection system.

The results of the fuzzy logic technique was presented at the “Industrial Automation” conference, in Montreal Canada, June 1999. Due to a patent application, further publications of the results of this work are put on hold.